MODELING THE SHIP AS A WEAPON SYSTEM

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Abstract

Viewing a ship as a weapon system is not a new concept. An excellent example is the Fleet Ballistic Missile (FBM) Submarine. Within its community, the FBM is perceived as a weapon system consisting of the weapon subsystem, the navigation subsystem, and the ship subsystem. There are good engineering reasons for this view: allocating resources, organizing information, and providing coordination. Further, as a weapon system the ship must respond to weapons execution orders as well as direction from all safety and protective systems. In practice, all warships are designed as weapons systems but the integration of their systems varies within wide limits. The net result is that weapon system performance may become decoupled from key ship design factors. In addition to the failure to achieve the necessary integration of the weapons subsystem components, weapon system performance may be considered to be synonymous with mission success at the expense of understanding those factors necessary for mission survival. This paper presents a model of a ship as a weapons system that provides a framework for the trade studies that impact the ship. It characterizes both the offensive and defensive interactions with the environment and provides context for the development of the ship's subsystems.

Introduction

This paper is a result of the author's experience with the ship design and integration process. The exposure has been as a result of integrating two combat systems and leading a radar design team developing a family of sensors for a future platform. The overall impression from these experiences is that the ship design process is a series of compromises that are evidenced by the allocation of degradation of performance rather than to improvement of performance. There are several reasons for this perspective. First the combat system decisions were made in a vacuum with the basic ship parameters set before the combat systems elements were selected. The common paradigm of the ship design process is the design spiral. It typically starts with ship parameters and can be very restrictive in that the combat system elements were selected as a compromise to accommodate weight, power, cooling

and manning restrictions resulting from the pre-selection of a ship design. Second, this approach does not factor in the requirements of the ship to participate as an integral subsystem of the Battle Force. There is no model that the author is aware of that could have produced the needed parametric examination between weapons system performance and its impact on the ship size and cost.

It is the premise of this paper that the ship should be treated as a weapon system within the larger concept of a family of systems comprised of the elements of the battle force.[1] This approach is consistent with a top down systems engineering approach such as that shown in Figure 1.
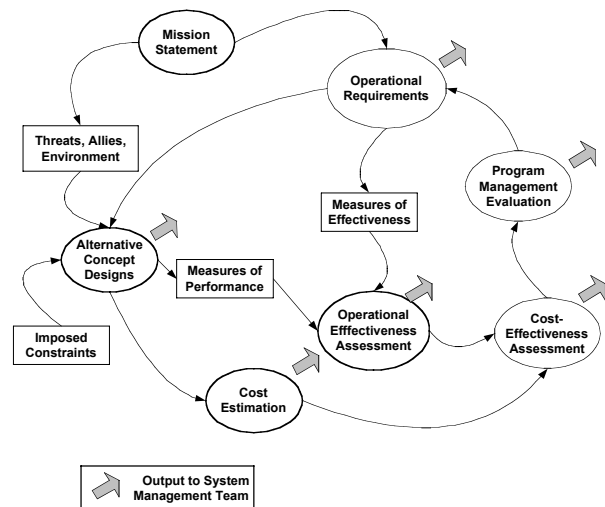
Figure 1. The Early Ship Design Process (Hockberger, 1996)

Treating the ship as a weapon system focuses on the key trade studies that are drive by performance requirements from both the sensor and combat system point of view. It is a weapon system design problem rather than a naval architecture problem. Revising the spiral model to start with the weapon system and its attributes leads to combat capability design solutions in

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[1] The views expressed in this paper are those of the author and do not necessarily reflect those of Raytheon.

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Abstract

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terms of performance, speed, and endurance and mechanical system design solutions in terms of equipment and spatial relationships. The focus is on areas that lead to successful mission performance. The model also address factors that could lead to mission failure. The result is a process model that addresses weapon system performance hand in hand with the naval architecture design, not as an ad hoc afterthought.

The Ship as a Weapons System

Addressing the ship as a weapons system is to recognize the old navy maxim that warships have the need to "sail in harm's way". The ship has to both perform in its environment and survive in its environment. Thus we have to look at the problem from two points of view:

- Offensive – mission accomplishment, and
- Defensive – survive to accomplish the mission

Within this context the purpose of the ship is to contribute to the mission success of the Battle Group and as such has performance attributes allocated to it as determined by its role within the larger system. It may well be that the ship has independent roles or missions as well. Either way mission success at the ship level is influenced by a number of factors including:

- The availability of the system for the mission;
- Platform performance qualities;
- Target acquisition capabilities;
- Type, effectiveness, and number of weapons;
- Command and Control capabilities;
- Platform signature and countermeasures;
- Tactics used and the operational environment; and
- The ability to take a hit and survive.

Thus mission success can be defined as the probability that the system will operate successfully under specific conditions throughout a given time period. This can be expressed as follows:

$$\textbf{Mission Success} = \textbf{A}_O\textbf{*R}_M\textbf{*S*MAM}$$

Where: A_O = mission availability; R_M = mission reliability; S (survivability) = probability of ship loss; and MAM = mission attainment measure (Marshall, 1991).

Mission availability and mission reliability follow from standard reliability theory definition. Survivability and the mission attainment measure are more complex and depend on a number of factors.

Survivability

Survivability: that feature which enhances the ship's ability to survive in a combat environment and to emerge as a still effective fighting unit. From the weapons system perspective this means taking damage and still being able to perform the assigned mission. The USS STARK and the USS COLE are two outstanding examples of survival after extensive damage. However, in both cases they were mission kills even though the ship was saved.

As can be seen from Figure 2, survivability is related directly to susceptibility and vulnerability. Susceptibility incorporates all factors that determine the probability that the ship will be damaged by any given threat. Vulnerability includes all factors that determine the degradation of any given mission area given a damage mechanism.

The left side of Figure 2 is known as the threat kill chain. Disruption of this kill chain is a key defensive requirement for the weapons system. Addressing three areas can reduce susceptibility:

- Decreasing the ability of the threat to detect (signature management);
- Improving the weapons systems ability to counter the target; and
- Disrupting the threat's ability to attack (countermeasures)

Reducing vulnerability requires control of the factors that impact the damage tolerance of the system. Appropriate reduction measures can be accomplished through ship arrangements.

- More compartments at center of ship
- Use of redundancy
- Dispersal of resources
- More fire zones

Taken together the reduction of susceptibility and vulnerability are known as active and passive hardening where active is defense in depth and passive is distributed system elements

Figure 3 is an example for the AAW mission. It shows the factors for active and passive hardening for an anti-ship missile threat.

Addressing the ship as a weapon system provides the proper perspective to addressing the survivability issues.
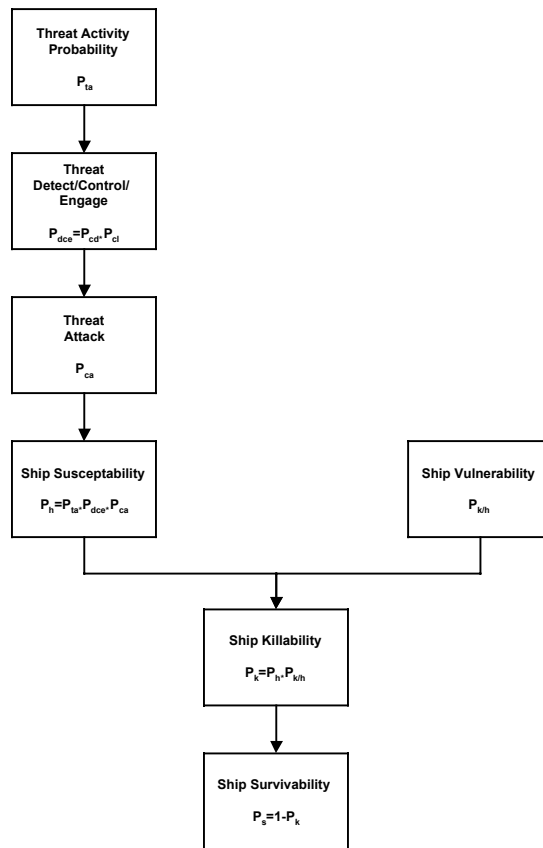
Threat Activity
Probability

P_{ta}

Threat
Detect/Control/
Engage

$P_{dce}=P_{cd} \cdot P_{cl}$

Threat
Attack

P_{ca}

Ship Susceptability

$P_h=P_{ta} \cdot P_{dce} \cdot P_{ca}$

Ship Vulnerability

$P_{k/h}$

Ship Killability

$P_k=P_h \cdot P_{k/h}$

Ship Survivability

$P_s=1-P_k$

Figure 2. The Factors in Survivability (Ball, 1985)

Detection Avoidance
- RCS Reduction
- IR Signature Reduction

Active Protection
- Threat Recognition
- Reaction Time
- Fire Power
- Deceptive Measures/ Decoys
- Sensors & Weapons

Passive Protection
- Location
- Separation
- Redundancy
- Shielding
- Armor

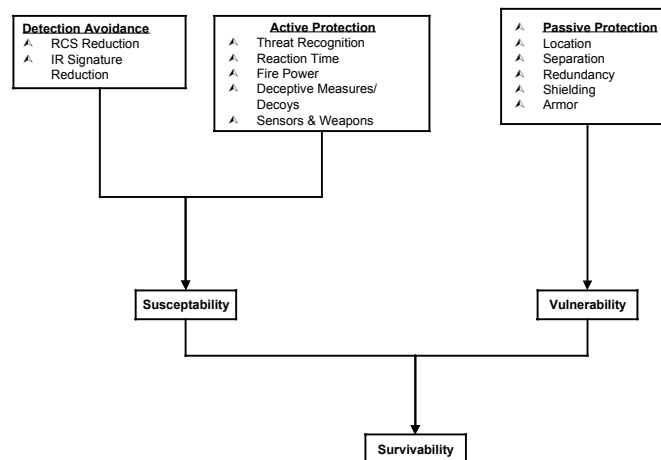Susceptability

Vulnerability

Survivability

Figure 3. Improving AAW Survivability

Mission Attainment Measure

The mission attainment measure (MAM) is the probability that the system will accomplish its objectives in the presence of the threat without regard to threat effects, i.e., it reflects the offensive capabilities of the weapon system.

In general MAM can be equated to weapon system effectiveness (WSE) where:

$$WSE = P_K \bullet P_D \bullet P_C \bullet P_E \bullet P_{WK}$$

The terms are defined as follows:
- P_D = probability of detection
- P_C = probability of control (correct identification, one track per target, etc)
- P_E = probability of engagement (the ability to guide the weapon to within its acquisition cone)

- P_{WK} = probability of weapon kill (the ability of the weapon to achieve the desired level of kill)

The mission success equation provides the basis for the process model that when used with a revised ship deign spiral model, incorporates weapon system performance with the ship design process.

Before describing the process model it would be instructive to present an example of the ship as a weapon system in the family-of-systems concept.

The Anti-Air Warfare Example

The Battle Force Anti-Air Warfare (AAW) problem is complex because of the varied capabilities required. Within this context both ships and aircraft are treated as weapons systems. Table 1 describes how the family of systems interact in the AAW environment.

	Outer Defense	Area Defense	Self- Defense
Sensors (range and position data)	Airborne long range	Sophisticated	Short range
Target capacity	Low capacity because of time on station and avail- ability and number of platforms	Large capacity because of range and time windows for engagement	Inherent low capacity because of range and time windows for engagement
Coverage	Sector coverage	Mutual support among escorts	Own ship
Threat	Engage enemy at long range (prior to enemy missile launch), counter enemy coordination, and jam enemy radars	Engage large, difficult threat	Engage residual threat

Table 1. Complementary Functions In Battle Group Air Defense

In this environment there are two categories of AAW threats:
- Those that the ship is designed to neutralize and
- Those that present a threat to the ship and its mission.

Assuming that the role of the ship as a weapons system is to provide area defense, the first threat category is the launch platform (e.g., an aircraft) and/or the anti-ship cruise missile (ASCM); the second category would be the ASCM (and/or the aircraft). In this role the weapon system is responsible for attacking the threat kill chain. The major elements of the threat

system's kill chain that can be attacked include detection and targeting sensors, a launch platform (that is not necessarily resident with the sensors), and the missile sensors. There are two methods for forcing a breakdown in the kill chain:
- Kill the detection/targeting platform and or the launch platform before launch; or
- Kill the missile after launch.

From the active and passive hardening perspective the self-defense, short-range engagement is the driving factor for survivability. Table 2 lists key survivability factors that must be accounted for in ship design.

Susceptibility Reduction	Vulnerability Reduction
Threat Warning	Component Redundancy (with separation)
Jamming and Deception	Component Location
Signature Reduction	Passive Damage Suppression
Threat Suppression	Active Damage Control
Decoys	Component Shielding
Tactics	Component Elimination

Table 2. Survivability Factors: ASCM Attack

The Process Model

Figure 4 is a process model that is based on the author's experiences with integrating weapons systems with ships. The inputs to the process are the mission, expected threat, environment and potential system concepts. Candidate systems can then be evaluated in the mission context for performance. This approach factors in each of the terms in the mission success equation. The focus is on the mission and potential system solutions. Operational availability, reliability, survivability, and weapons systems performance can be related to their subsequent impact on ship design. The approach is balanced between those elements, both combat system and ship systems, that are required for mission success. At this point the design can be evaluated against potential ship design constraints.

Using the AAW example, there is a desired protective envelope around the battle force (and own ship), the size of which is a function of threat characteristics, own force sensors, command and control reaction time, and weapons. A large envelope requires long-range threat detection, which in turn implies a requirement for high power radars. High power radars provide the desired performance but their use implies large cooling and power sources. The net impact on ship design in terms of antenna location, weight, volume, power, cooling, and manning can be evaluated against desired performance. Repeating this type of analysis for all subsystems leads to a baseline ship design.
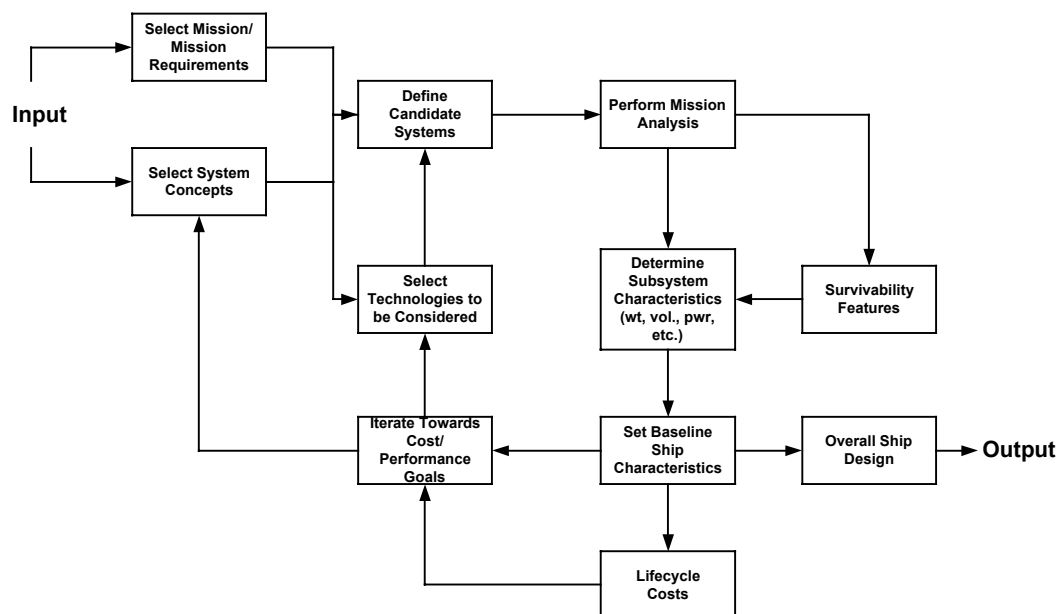

Figure 4. Designing the Ship as a Weapons System

At this point in the process the design is iterated against the constraints. Using this approach with the conceptual ship design stated as a goal is more effective than using the ship design as a constraint.

In the design of the combat system for a foreign navy the author had to work within the constraints of a FFG7 design whereas with the Norwegian design the paradigm of Figure 4 was followed. The result was a frigate-sized ship with a variant of the AEGIS combat system. This solution would not have been possible had the ship type been specified first.

Summary
Mission success for a ship in a battle force depends on two major factors: its ability to perform its offensive mission and it ability to survive the threat's attempts to thwart it in the performance of its role. Viewing the ship as a weapons system keeps these performance goals in context with the assigned missions. Also, considering the ship as a weapons system provides a clear understanding that survivability is an integral element of mission success. It places the concepts of active and passive hardening in context along with desired system performance. The process model that results from this view of the ship focuses on the mission goals rather than starting with a set of constraints and accepting degradation in the performance of these goals as a price that must be paid.

Biography
Mr. Green is a Senior Principal Systems Engineer at Raytheon Naval and Marine Information Systems. Previously he was the Technical Director for Lockheed martins Norwegian Frigate Concept and was the Combat Systems Engineer for a Frigate design for another foreign navy. He is experienced with AEGIS and SSDS MK2 and was a qualified SSBN Weapons Officer.

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